Status of ENDF/B-VII.1

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ENDF/B-VII.0 ➔ ENDF/B-VII.1

Release December 2011
5 years after ENDF/B-VII.0

332 citations
(SCOPUS)

Release December 2006
16 years after ENDF/B-VI

Wednesday, May 11, 2011
Major Changes in ENDF/B-VII.1

1. Covariances (VII.0: 4% => VII.1: 40%) (BNL, ORNL, LANL)
2. Light nuclei based on R matrix work at LANL (4He, 6Li, 9Be, 16O)
3. Structural materials:
   3.1. New evaluations – supported by criticality safety (ORNL)
   3.2. Improvements to thermal cross sections (BNL)
4. Pu fission products yields (LANL)
5. Delayed neutrons reverted to VI.8 (LANL)
6. Actinides – a few new evaluations for minor actinides, improvements to fission, capture, (n2n) using feedback from critical assembly reaction rate data, and data from LANSCE, CERN etc (LANL)
7. Many new JENDL-4 data adopted for Minor Actinides
<table>
<thead>
<tr>
<th>Description</th>
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<tr>
<td>Total number of materials</td>
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<tr>
<td>New or revised materials</td>
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<tr>
<td>Totally or partially new materials</td>
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<td>- LANL</td>
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<td>- LANL/ORNL</td>
<td>8</td>
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<tr>
<td>- ORNL</td>
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<td>- ORNL/IAEA</td>
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<tr>
<td>- BNL</td>
<td>3</td>
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<tr>
<td>- LLNL</td>
<td>8</td>
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<tr>
<td>- IRMM (Geel, Belgium)</td>
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<td>Thermal x-sec adjustment BNL</td>
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<td>Other fixes</td>
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<td>- JENDL-3.3 (R.Q. Wright corr.)</td>
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<td>- JENDL-4.0</td>
<td>69</td>
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<td>- JEFF-3.3 (R.Q. Wright corr.)</td>
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</table>
New or partially new evaluations in beta2

- **He-4**  New R-matrix analysis by LANL
- **Li-6**   New R-matrix evaluation by LANL using WNR data
- **Be-9**   New evaluation by LANL
- **O-16**   New R-matrix evaluation by LANL including covariances
- **F-19**   New MF2/32 evaluation by ORNL
- **Na-23**  New full range evaluation by BNL
- **Cl-35**  New R-Matrix Limited MF2/32 evaluation by ORNL
- **Cl-37**  New MF2/32 evaluation by ORNL
- **K-39**   New MF2/32 evaluation by ORNL
- **K-41**   New MF2/32 evaluation by ORNL
- **Ti-46**  New fast neutron region and covar. by LANL, new MF32 by ORNL
- **Ti-47**  New fast neutron region and covar. by LANL, new MF32 by ORNL
- **Ti-48**  New fast neutron region and covar. by LANL, new MF32 by ORNL
- **Ti-49**  New fast neutron region and covar. by LANL, new MF32 by ORNL
- **Ti-50**  New fast neutron region and covar. by LANL, new MF32 by ORNL
New or partially new evaluations in beta2

- V-51  New fast neutron region and covariances by LANL, MF2 from JENDL-4
- Cr-50  New MF2/32 by ORNL
- Cr-52  New MF2/32 by ORNL
- Cr-53  New MF2/32 by ORNL
- Cr-54  New MF2/32 by ORNL
- Mn-55  New MF2/32 by ORNL, new fast neutron region and covar. by IAEA
- Ni-58  New MF2/32 by ORNL, updated a-production, various corrections
- Ni-62  New MF2 evaluation by BNL
- Kr-78  New fast neutron region by LLNL merged with MF2 from ENDF/B-VII.0
- Y-89   New evaluation for total and capture by LANL
- Zr-90  New MF2 by BNL, bound level at -234 keV removed
- Xe-123, 124  New fast neutron region by LLNL, various fixes by BNL
- Ta-180, 181  New fast neutron region by LLNL, various fixes by BNL
New or partially new evaluations in beta2

- **W-180, 182, 183, 184, 186** New MF2/32 by ORNL, new fast neutron region + covariances by IAEA
- **Re-185, 187** New fast neutron region by LLNL with BNL fixes
- **U-235** LANL reverted dn 6-grp to ENDF/B-VI.8, new MF33 evaluation by ORNL/LANL, PFNS (MF5,MT18) on finer grid
- **U-237** New LANL (Phil Young) fast neutron region and dn 6-grp reverted to ENDF/B-VI.8
- **U-238** LANL reverted dn 6-grp to ENDF/B-VI.8, new MF33 evaluation by ORNL/LANL
- **U-239** New fast neutron region by LLNL with MF2 estimated by A. Trkov BNL
- **Pu-238** New fast neutron region by LANL (P.G.Young et al.)
- **Pu-239** New MF35,MF31,PFNS by LANL, new MF33 by ORNL/LANL, LANL reverted dn 6-grp to ENDF/B-VI.8, BNL extended URR to 30keV,
- **Pu-240** New fast neutron region by LANL including MF31,33,35
- **Am-241** New evaluation and covariance matrices by T. Kawano LANL
Comparisons with Exptl. Data

n$^+\text{O}$ Total Cross Section

$\sigma_T$ (b) vs $E_n$ (MeV)

$\sigma_T$ (b) vs $E_n$ (MeV)

$^{13}\text{C}(\alpha,n)$ Cross Section

$\sigma_{\alpha,n}$ (b) vs $E_\alpha$ (MeV)

$\sigma_{\alpha,n}$ (b) vs $E_\alpha$ (MeV)
Comparisons with ENDF/B VII.0

\[ \sigma_n^{16}O \text{ Total Cross Section} \]

\[ \sigma_n^{16}(n,n)^{16}O \text{ Cross Section} \]

\[ \sigma_n^{16}(n,\alpha)^{13}C \text{ Cross Section} \]
Status of VII.1 for $^{16}$O

- Small changes in $\sigma_{el}$ and $\sigma_{tot}$ at energies below 7.5 MeV.

- Scale of $\sigma_{n\alpha}$ cross section increased about 35% below 9 MeV, putting it back about where it was before the previous change.

- All cross sections unchanged above 9 MeV.

- Preliminary testing in aqueous solutions gives little change in the crits; “broomstick”, especially sensitive to the cross sections in the 2.35-MeV window, is yet to be completed.

- Detailed covariances are given for the major cross sections, and for the first Legendre coefficient (mu-bar).
n\textsuperscript{+}\textsuperscript{9Be} Total Cross Section

ENDF/A VII.1:

- “Glitch” in $\sigma_{\text{tot}}$ removed
- Better fit to RPI data below 500 keV
The $L = 1$ component of the Legendre expansion coefficients for the differential elastic scattering from 48Ti, as a function of neutron incident energy.

Calculated $P_1$ (the $L = 1$ component of the Legendre expansion coefficients) for the differential elastic scattering tends to overestimate reflection of neutrons in the critical assemblies with a Ti reflector, and adjustment of the optical potential parameters does not solve this problem. This was finally resolved by replacing the elastic scattering angular distributions of 48Ti up to 4 MeV by those in ENDF/B-VI.8
Comparisons of capture cross-section on 55-Mn calculated with ENDF/B-VII.0 and ENDF/B-VII.1.
55-Mn
new ORNL/IAEA/JSI evaluation

Grenoble lead-slowing down benchmark data for 55Mn sample (blue squares) vs calculations using ENDF/B-VII.0 (green line) and ENDF/B-VII.1 (red line).
covariances are given elsewhere. All evaluations include covariance information obtained herein.

mentioned discrepancies and the availability of new data total cross section data for separated tungsten isotopes tematic discrepancies were observed in criticality safety factory during recent data validation and assessment: sys- ENDF-B/V evaluations were later extended up to 150 challenging as pointed out by evaluators at the time [92].

consistent description of high-current accelerators, as well as neutron dosimeter wall components in fusion devices, target and beam win-

comments on the status of ENDF-B/VII.0 ENDf/B-VII.1

However, the status of the data was considered unsatis-

184 W was corrected. The capture background was 

[101]. Calculated results were compared 

timated uncertainty of the vertical scale (around 0.02)

experimental data were shifted down -0.008, while OMP 

vided by the average total cross section) of 

Table 1 at p.15 of NEMEA-3 proceedings [104, 105]). A 

cos (n,n') reaction. Evaluations of tungsten 

W iso-

[101]. Neutron induced reactions on 

W.

184

182

182

231

232

Mn – up

W.

28

58

197

93

32

59

1958 Booth

1959 Johnsrud

1965 Chaubey

1966 Block

1966 Konorov

1981 Pasechnik

1983 Macdonald

1984 Vedernikov

1984 Beghin

1987 Trofimov

1987 Knopf

1988 Konorov

1989 Makin

1990 Konorov

1990 Magnussen

1991 Snyder

1992 Ndlovu

1993 Daily

1994 Beghin

1995 Belousov

1996 Agra

1996 Konorov

1997 Retief

1997 Snyder

1997 Trofimov

1998 Belousov

1998 Scharf

2000 Orlova

2000 Orlova

2001 Orlova

2002 Orlova

2003 Dietrich

2004 Vuong Huu Tan

2005 Orlova

2005 Orlova

2006 Orlova

2007 Orlova

2008 Orlova

2009 Orlova

2010 Orlova

2011 Orlova

2012 Orlova

2013 Orlova

2014 Orlova

2015 Orlova

2016 Orlova

2017 Orlova

2018 Orlova

2019 Orlova

1 10

9 10

10

5

-5

5

-5

2 10

3 10

4 10

ND

5

6

7

8

9

10

f

10

f

10

f

10

f

10
89-Y partial LANL evaluation

![Graph showing neutron capture cross section vs. energy for 89-Y partial LANL evaluation.](image)

ENDF/B-VII.0 70group
ENDF/B-VII.1 70group
Boldeman

Neutron Incident Energy [MeV]
Capture Cross Section [b]

Discrepancy-SOFT
Discrepancy-PWR

<table>
<thead>
<tr>
<th>Element</th>
<th>Discrepancy-SOFT</th>
<th>Discrepancy-PWR</th>
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<tbody>
<tr>
<td>Tc</td>
<td>+13</td>
<td>-1</td>
</tr>
<tr>
<td>Mo</td>
<td>+11</td>
<td>-6</td>
</tr>
<tr>
<td>Sm</td>
<td>+10</td>
<td>-6</td>
</tr>
<tr>
<td>Eu</td>
<td>+9</td>
<td>0</td>
</tr>
<tr>
<td>Sm</td>
<td>+3</td>
<td>-6</td>
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<tr>
<td>Sm</td>
<td>+2</td>
<td>0</td>
</tr>
<tr>
<td>Tc</td>
<td>+1</td>
<td>0</td>
</tr>
<tr>
<td>Mo</td>
<td>+1</td>
<td>0</td>
</tr>
</tbody>
</table>

ENDF/B-VII.0 thermal capture cross section of 89-Y is 13.56 b, which is large by about 9%.
237-Np
improvement of (n,2n) by LANL

To summarize this section, the 2200 m/s cross sections and resonance integrals of ENDF/B-VII.1 and ENDF/B-VII.0 are collected in Table XVIII to highlight the changes made in these quantities. The following points have been achieved.

- Except for $^{95}\text{Mo}$, the major significant discrepancies of the reactivity-worth results of [115] are removed in the ENDF/B-VII.1 evaluations.
- The $^{62}\text{Ni}$ capture cross section was reevaluated so that the computed ENDF/B-VII.1 30-keV Maxwellian capture cross section agreed with direct measurements.
- The thermal capture cross sections of $^{90}\text{Zr}$ and $^{91}\text{Zr}$ are reevaluated on account of a new measurement and those of $^{113}\text{Cd}$ and $^{157}\text{Gd}$ modified to reflect recent differential and integral measurements.

F. Actinides
1. $^{232}\text{Th}$

No changes have been made for VII.1 as compared to VII.0. Nevertheless, below we (R. Capote) make some observations on the assessment of our thorium evaluation.

The most precise fast neutron benchmark involving thorium is the THOR assembly, which is described in the ICSBEP compilation as PU-MET-FAST-008 [109]. It is a plutonium sphere in a cylindrical thorium reflector. It is quoted with an experimental uncertainty of 60 pcm due to the uncertainty in the critical mass. We believe that the uncertainty quoted for this benchmark is underestimated. The criticality of this benchmark is underpredicted by about 200 pcm with ENDF-B/VII.0 thorium data. Substitution of ENDF-B/VII.0 $^{232}\text{Th}$ data with JENDL-4, in which the fission cross section from 1.2 to 5 MeV is higher by about 8 %, improves the criticality prediction, but not the reaction rate ratios, which were also measured for this benchmark. Additionally, the Comet assembly of a U-sphere with Th reflector (HEU-MET-FAST-085 case 5) does not show the same trend in $k_{\text{eff}}$, although the Comet benchmark uncertainty is higher. Plots of criticality benchmarks in ICSBEP relevant to $^{232}\text{Th}$ data can be found in a companion paper by Kahler et al. in this edition [107].

Since the observed discrepancies are somehow contradictory, and the underprediction of reactivity is not so outstanding, we choose to stick with the present ENDF-B/VII.0 evaluation.

It should be also noted that an IAEA coordinated research project on prompt fission neutron spectra (PFNS) [143, 144] is ongoing; this new research project will undoubtedly have an impact on actinide evaluations including thorium. Considering the sensitivity of criticality benchmarks to PFNS and a subtle interplay in fast metallic benchmarks between nubar, PFNS and cross sections, it is sensible to wait for results of the PFNS project before reevaluating $^{232}\text{Th}$ ENDF-B/VII.0 cross-section data.

2. $^{237}\text{Np}$

The $^{237}\text{Np}$ evaluation has been updated using a recent evaluation of Maslov et al. Their evaluation concentrated on the production of the short-lived $^{236}\text{Np}$ isomer and replaces the (n,2n) and (n,3n) cross sections. Figure 32 compares the ENDF/B-VII.1 evaluations to both the previous evaluation ENDF/B evaluation and available experimental data. As can be seen, the new (n,2n) evaluation (solid black) corrects unphysical behavior near threshold of the previous ENDF/B-VII.0 evaluation (black dashed). Additionally, the new evaluation well reproduces experimental data for both the total (n,2n) (black circles) and production of $^{236}(s)\text{Np}$ (blue circles).

Corrections to the $^{237}\text{Np}$ evaluation also include new resonance parameters fitted to the thermal (n,γ) cross section of Mughabghab; $\sigma_0\gamma = 175.9 \pm 2.9 b$, figure yyy.
236-U
partial LANL reevaluation (n,g) & (n,f)

ENDF/B-VII.0 compared with ENDF/B-VII.0 and experimental data from the LANL SCE/DANCE detector.
239-U new LLNL evaluation

![Graph showing 239-U(n,f) cross section comparison between different evaluations and data points.](image)

The ENDF work on uranium-239 is summarized here, with more details available in Brown's paper [1]. The original ENDF/B-VII.0 evaluation was based on Behrens' scale factor up to 30 MeV [3]. Fortunately, in the years since ENDF/B-VII.0 was released our knowledge of what under studied. Indeed, ENDF/B-VII.0 was the first ENDF-series library to contain an evaluation of this very important nucleus.

The original ENDF/B-VII.0 evaluation was based on Behrens (n,f) systematics [148]. The surrogate analysis of Ref. [145] matches nicely with the 1977 systematics by Behrens [148].

The surrogate analysis of Ref. [145] matches nicely with the 1977 systematics by Behrens [148].

All high energy cross section data are based on GNASH calculations which were tuned to reproduce Behrens (n,f) systematics. As we have changed the fission cross section, we must correct the remaining high-energy cross sections so that uncertainties and are not including them in the evaluation underpins the second and third chance fission, respectively. Given the crudity of these uncertainties and are not including them in the evaluation, we assign 20% and 25% uncertainties to second and third chance fission respectively. Given the crudity of these uncertainties and are not including them in the evaluation, we assign 20% and 25% uncertainties to second and third chance fission, respectively.

To perform our reanalyses of Younes and Britt [145, 146] with the new (t,pf) and (p,2n) surrogate reaction experiments performed by Burke et al. [147]. In all three cases, the data [145, 146] and new surrogate reaction experiments have made a new evaluation of surrogate reactions create the same compound nucleus (2009) J. Burke, et al. (2005) Younes & Britt

Our new (n,f) cross section evaluation combines the original Younes and Britt surrogate analysis [145] and the 1977 systematics by Behrens [148].

The resonances are taken from the ENDF/B-VII.0 evaluation. The resonances are taken from the ENDF/B-VII.0 evaluation. The resonances are taken from the ENDF/B-VII.0 evaluation.
239-U
new LLNL evaluation

FIG. 35: Comparison of the new ENDF/B-VII.1 evaluation with the ENDF/B-VII.0 evaluation in the resonance region for the (n,n\textsuperscript{0}) channel.

FIG. 36: Comparison of the new ENDF/B-VII.1 evaluation with the ENDF/B-VII.0 evaluation in the resonance region for the (n,tot), (n,el), (n,f) and (n,\gamma) channels.

The resonance region in the original ENDF/B-VII.0 evaluation has several deficiencies:

- The thermal cross sections did not match systematically high with the ENDF/B-VII.0 evaluation.
- The cross sections are uniformly high: the Westcott factor is 4, which is unusually high (the Weisskopf-Ewing limit and that the contribution from the compound elastic is negligible. With these assumptions, the reaction cross sections add up to the reaction cross section.

To correct these problems, A. Trkov generated a new MBC-probably delete next sentence: Given that the resonance region was taken from the unresolved resonance parameters may not be useful. The thermal cross section and resonance evaluations from Ref. [150].

The processing code NJOY-99.360 reported a NaN (not a number) for the thermal eta integral value. Because the resonance region was taken unchanged, from the resolved resonance region using EMPIRE in the BROADR module [152].

The resonance region was taken simply by "picket fence" resolution of the resonance region using EMPIRE evaluation, it is likely that the location of each resonance was set.

The final cross-sections are shown in Fig. 35.
239-U thermal & resonance region

“Picket fence” resolved resonance region generated by EMPIRE. Resonance set at energies

\[
\text{Etherm} + nD0/2
\]

where \( n = [-2, -1, 1, 2, \ldots] \).

D0 is the average level spacing given by Mughabghab.

Widths of resonances tuned match average capture and fission widths.

Average elastic width remains close to the value from the 237U evaluation.
The ENDF work on plutonium-238 is summarized here, with more details available in Talou, Young, et al.'s paper [8]. A new evaluation was performed for neutron-induced reactions on Pu-238 in the fast neutron region. The evaluation is based on model calculations, as well as analysis of experimental data. The ECIS94 code [154] was used to perform coupled-channels optical model calculations, and obtain total, shape and reaction cross sections, as well as all discrete elastic and inelastic cross sections and angular distributions. Neutron transmission coefficients used for statistical Hauser-Feshbach calculations were also inferred from the coupled-channels results. The optical model potential developed recently by Soukhovitskii et al. for even-even plutonium isotopes [155] was used in this work.

The GNASH [156] and COMNUC [157] codes, which implement the Hauser-Feshbach equations, width fluctuation corrections as well as pre-equilibrium components, were used to compute \((n, x n)\) reaction cross sections. The COH code [158] was used for computing the neutron radiative capture cross section. The GLUCS statistical analysis code [159] was used to analyze experimental data sets, and in particular, infer the fission cross section as well as prompt fission neutron multiplicity.

The JENDL-4.0 evaluation [160] was also used to complement the present work in certain areas. In the following, we have compared the new VII.1 evaluation to other evaluations, ENDF/B-VII.0, JENDL-4.0 and JEFF-3.1. The ENDF/B-VII.0 evaluation is more than 30 years old, carried from ENDF/B-V. The JEFF-3.1 evaluation was mostly taken from JENDL-3.2, and the unresolved resonance parameters were taken from BROND-2.2. The JENDL-4.0 is the most recent evaluation from JAEA, including modern coupled-channels calculations, new set of resolved resonance parameters, and covariance data.

Total, Elastic, Non-Elastic and \((n, x n)\) Reaction Cross-Sections

Below 60 keV, the resonance parameters evaluated in JENDL-4.0 were adopted [160]. The shape and magnitude of the cross sections below 60 keV however are consistent with the Soukhovitskii optical model calculations, and only a very small adjustment was required for joining the cross sections at 60 keV. From 60 keV up to 30 MeV, the total cross section results entirely from the coupled-channels calculations using the Soukhovitskii potential [155].

Our evaluated \(n^+\)\(^{238}\)Pu total cross section is compared in Fig. 37 to the ENDF/B-VII.0, the JEFF-3.1, and the JENDL-4.0 evaluations between 0 and 20 MeV. Our results are in very close agreement with the JENDL-4.0 data. In Fig. 38 we compare our results with the same evaluations and the experimental data of T.E. Young et al. [163] in the resonance range. Again, good consistency with the JENDL-4.0 evaluation above 60 keV is apparent. Below 60 keV we adopted the JENDL-4.0 resonance parameters, so the two evaluations are identical.

The non-elastic cross-section is inferred by summing the inelastic, \((n, x n)\), fission and capture cross sections. The non-elastic cross section is compared to other evaluations in Fig. 39.

The elastic cross section, which is the sum of shape and compound nucleus components, is obtained by subtracting the non-elastic cross section from the total cross-section, and is shown in Fig. 40, together with the ENDF/B-VII.0, the JEFF-3.1, and the JENDL-4.0 evaluations.

The total inelastic cross section is simply the sum of...
238-Pu(n,inel) & 238-Pu(n,2n) note discrepancies among libraries

- As mentioned above, optical model coupled-channel calculations were performed using the ECIS96 code [154].
- For this reaction, compared to other major evaluations. No experimental data exist for this reaction.
- They neglect the contribution from pre-equilibrium neutrons, as well as JEFF-3.1. Again, this large difference compared to other major evaluations. No experimental data exist for this reaction.
- For this reaction, compared to other major evaluations. No experimental data exist for this reaction.
- Overall, twenty-one states were included in the optical model calculations. The deformation parameters were taken from Soukhovitskii for Pu.
- Both ENDF/B-VII.1 and JENDL-4.0 evaluations show a pronounced dip near 5 MeV, due in part to a minimum in the fission cross section.
- The (n,3n) cross section is illustrated in Fig. 43. Again, our evaluation is compared to the other evaluations, which tend to increase the tail of the (n,n') cross section at the expense of the (n,2n) cross section.
- The (n,3n) cross section is illustrated in Fig. 43. Again, our evaluation is compared to the other evaluations, which tend to increase the tail of the (n,n') cross section at the expense of the (n,2n) cross section.
- As mentioned above, optical model coupled-channel calculations were performed using the ECIS96 code [154].
- Overall, twenty-one states were included in the optical model calculations. The deformation parameters were taken from Soukhovitskii for Pu.
Nonetheless, a small dip still occurs in the nonelastic cross smoother result for the elastic cross section (see Fig. 40). We have smoothed-out this result to obtain a to a few data sets pulling the least-square result down results except at the dip observed near 5 MeV, which is due ENDF/B-VII.1 evaluation follows exactly the GLUCS re-

The result of the GLUCS covariance analysis of experi-

mental data points. The ENDF/B-VII.1 evaluation (red solid curve) follows the GLUCS results, except at the dip near 5 MeV.
238-Pu prompt fission neutron spectrum
new LANL evaluation

FIG. 48: The calculated prompt fission neutron spectrum of 238Pu for thermal neutrons is plotted as a ratio to a Maxwellian at temperature T=1.33 MeV (== ENDF/B-VII.0). The results from ENDF/B-VII.0, JENDL-4.0, and JEFF-3.1 evaluations are shown for comparison.

FIG. 49: The ENDF/B-VII.1 multi-chance fission probabilities for the n+238Pu were calculated with the GNASH code, and compared to the ENDF/B-VII.0, JENDL-4.0 and JEFF-3.1 evaluations. Since there is no experimental measurement of the n+238Pu PFNS, it is difficult to state which one is closer to the truth than the others. In this specific case, the spread in the different evaluations can be used as an estimator of PFNS uncertainties.

At higher energies, multi-chance fission occurs, and has to be taken into account in the evaluation process. As the ENDF/B-VII.0 evaluation represents all PFNS from thermal to 20 MeV as a single Maxwellian at a given temperature, it is lacking the important multi-chance fission component. The ENDF/B-VII.1 evaluation corrects this defect by including multi-chance fission probabilities calculated with the GNASH code, as shown in Fig. 49.

Note that while the multi-chance fission probabilities were in fact calculated in ENDF/B-VII.0, they were not used for evaluating the prompt fission neutron spectra at higher energies. Also, the ENDF/B-VII.0 multi-chance fission probabilities look dubious, as the first-chance fission probability flattens out past the neutron separation energy, as opposed to decreasing while the second-chance fission increases. The same observation can be made for higher-order fission probabilities.

The PFNS calculated for 20.0 MeV incident neutron energies is shown in Fig. 50, and compared with other evaluations. The ENDF/B-VII.1 result is in fair agreement with JENDL-4.0 and JEFF-3.1, and deviates significantly from the older ENDF/B-VII.0 evaluation.

The average prompt fission neutron multiplicity (PFNM) was also evaluated using the Madland-Nix model. Experimental data on PFNM exist for thermal neutrons only: Jaafey and Lerner [170] and Kroshkin and Zamjatnin [171]. Our calculated result is shown in Fig. 51, in comparison with other evaluations. Again, since no experimental result exists for this quantity beyond the thermal value, it is difficult to make a good case for one particular result. Additional work based on systematics over suites of isotopes is needed to better constrain those unmeasured quantities. However, since our evaluation uses the model parameter systematics established by Tudora [169], which encompasses many actinides, the ENDF/B-VII.1 result should be reasonable.

At present we are not making substantive changes for the 239Pu evaluation, other than reverting to ENDF/B-VI.8 delayed neutron parameters for the reasons discussed in Sec. VI G. The previous prompt fission neutron spectrum from Madland has been carried over to ENDF/B-VII.1 but with a finer outgoing neutron energy representation. Ongoing work on 239Pu that will be made available in future ENDF releases is summarized in Sec. XI. This includes ongoing work on the prompt fission...
240-Pu(n,tot) new LANL evaluation

240 Pu Total Cross Section

Incident Neutron Energy (MeV)

Total Cross Section (b)

0.01 0.1 1 10

240 Pu Total Cross Section

Smith, 1972
Poenitz, 1981
Poenitz, 1983
ENDF/B-VII.1
ENDF/B-VII.0
JENDL-4.0
JEFF-3.1

Total, Elastic, Non-Elastic and \((n, xn)\) Reaction Cross-Sections

Between 0 and 40 keV incident neutron energies, the total cross section was obtained from the JENDL Actinoid evaluation [160], but were renormalized slightly to match the covariance analysis of experimental data above 40 keV. The shape of the cross sections below 40 keV follows the Sukovitskii optical model calculation closely. The evaluation of the neutron total cross section in the MeV region resulted from a covariance analysis with the GLUCS code [159] of the experimental data. Experimental data used were those of Poenitz, Whalen and Smith [172], Poenitz and Whalen [173], and Smith, Whalen and Lambropoulos [174]. We used the optical model results from our modified version of the Sukhovitskii potential [155] as the prior in the GLUCS analysis, and the analysis results are very close to the optical model values at all energies. The evaluated total cross section is a smooth curve through the covariance analysis results, and above 8 MeV is identically equal to the optical model calculation.

The elastic cross section was obtained by subtracting the non-elastic cross section from the total cross section. It is consistent with the modified Soukhovitskii optical results. The non-elastic cross section is the sum of the total inelastic \((n,n')\), \((n,2n)\), \((n,3n)\), \((n,4n)\), \((n,\gamma)\) and \((n,\gamma)\) cross sections. The \((n, xn)\) cross sections (and energy-angle distributions) result from our GNASH calculations. The \((n,2n)\) cross section is shown in Fig. 55 in comparison with other evaluations. The ENDF/B-VII.1 result is somewhat higher near 14 MeV than the earlier ENDF/B-VII.0, JEFF-3.1, and JENDL-3.3 evaluations but is lower than the JENDL-4.0 evaluation [160]. Overall, however...
240-Pu nu-bar
new LANL evaluation

**FIG. 58:** Experimental data on the ratio of neutron-induced fission cross sections of Pu-240 over U-235.

**FIG. 59:** Multi-chance fission components calculated for the total neutron-induced fission cross section of 238Pu.

GLUCS covariance analysis results. These results are influenced strongly by the extensive measurements of Staples and Morley [175]. At some energies in this range, the present evaluation differs appreciably from the ENDF/B-VII.0, JEFF-3.1, JENDL-3.3, and JENDL Actinoid evaluations. The GNASH analysis closely follows the evaluation at most energies.

At higher energies, the multi-chance fission cross sections are obtained by scaling the GNASH calculations by the ratio of the new evaluated total fission cross section to the GNASH total fission cross section. The multi-chance fission cross sections are shown in Fig. 59.

**Neutron Radiative Capture Cross Section**

From 0 to 30 keV, the radiative capture cross section is taken from the JENDL Actinoid evaluation [160], which is consistent near 30 keV with our GLUCS covariance analysis between 20 and 300 keV. From 30 to 400 keV, our evaluation is based on a smooth curve through the result of our covariance analysis of the available experimental data. The 0.4 to 2 MeV energy range is treated as a smooth transition of the data below 0.4 MeV to the ENDF/B-VII.0 evaluation at 2.0 MeV. And from 2 to 30 MeV, the evaluation is taken from the ENDF/B-VII.0 evaluation to 20 MeV and smoothly extrapolated to 30 MeV.

**Average Prompt Neutron Multiplicity (n/fission)**

The average prompt neutron multiplicity ν as a function of incident neutron energy is evaluated from a covariance analysis of existing experimental data. The ENDF/B-VII.1 evaluation is shown in Figs. 61 and 62 compared with experimental data and other evaluations.

To do: smooth-out small variations of ν due to GLUCS, above 1 MeV.

The Madland-Nix model [168] was used to evaluate the average prompt fission neutron spectrum and multiplicity.
240-Pu
new LANL evaluation

Good agreement with JENDL-4.0

ENDF/B-VII.1
ENDF/B-VII.0
JENDL-4.0
JEFF-3.1

FIG. 54: The 240 Pu elastic cross section is compared to other evaluations.

The inelastic continuum neutron cross section is based on the GNASH Hauser-Feshbach statistical/pre-equilibrium calculations, as described above. The total inelastic cross section is shown in Fig. 56 in comparison to other evaluations.

Neutron Elastic Scattering Angular Distributions
Coupled-channels calculations were used to calculate the elastic scattering angular distributions for the ground-state rotational band, as well as the compound nucleus angular distributions for the higher excited states. For the assumed collective 2+ and 3− states, the angular distributions were obtained from vibrational model calculations for the n+238 U reactions, as described above.

Fission Cross Sections
From 0 to 550 keV, the fission cross section was taken from the JENDL Actinoid evaluation [160]. These data agree well with the results of a GLUCS covariance analysis of the experimental data from 60 keV to 30 MeV, where they overlap.

From 550 keV to 30 MeV, the neutron-induced fission cross section is based on a smooth curve through the data.
ENDF/B-VII.1 beta2 verification at BNL

R. Arcilla

CHECKR

simple physics & conformance to recommended procedures

FIZCON

complicated physics

PSYCHE

producibility of ACE files for neutronics calculations

NJOY

ACE Files

ability to perform simple neutronics calculations (GODIVA)

MCNP

CONFORMANCE TO ENDF FORMAT


NNDC Linux Cluster

Brookhaven Science Associates
 Updates of checking codes were needed to process all new evaluations

 Checking VIEWR plots critical

 F-19 and Cl-35 (R-Matrix Limited format) need NJOY-2009 or -2010

 Help from LLNL - conversion of beta2 into XENDL format and back revealed hidden errors in VII.0 (MF14)
Thermal capture comparison

- low- and medium-Z:
  - poor experimental data (comparison of theoretical calculations)
  - He-3, Said adopted Wolfs data; VII.1 is in between Wolfs and Alfimenkov
  - Co-58 deficiency in VII.1
  - Zr-90 evaluation update

- high-Z region: new evaluations from the Actinoid file

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Brookhaven Science Associates
Maxwellian-averaged Cross Sections

(KADONIS / VII.1beta2)

- O-16, C-0 fixed in beta3
- Be-9 fixed in beta3
- He-3 deficiencies in the keV-region, fixed in beta3
- S-36, Ar-38, Se-82 no experimental data
- Ca-46,48 deficiencies would not affect ENDF validation
- small Cd-46,48 isotopic abundances
Corrections resulting from comparison

\[ \text{nat} C(n,g) \]

\[ 16O(n,g) \]

\[ 58Co(n,g) \]
Validation highlights

- **Be-9**: mixed improvement - some improved other worse
- **O-16**: good performance (at least as good as VII.0)
- **Ti**: improved
- **V-51**: improved
- **Mn-55**: improved
- **Cd**: mixed - k-eff improved but bias increased
- **W**: consistently improved
- **Gd-157**: mixed results but generally better
Covariances in ENDF/B-VII.1
AFCI effort by BNL and LANL

List of nuclei in AFCI (priority materials in **bold**)

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<td>AFCI/GNEP/COMMARA project - 110 covariances, serving as a reference for constructing ENDF-6 formatted covariance files for ENDF/B-VII.1</td>
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<td>BNL - structural materials, 23Na, minor actinides, and all the rest including RR.</td>
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Covariances in beta3 to be released in May 2011
Plans for beta3 and ENDF/B-VII.1

- SVN repository blocked May 4
- beta3 release ~May 16
- Full set of AFCI covariances in beta3
- beta3 = ENDF/B-VII.1 except covariance improvements and clerical fixes
- Substantive changes only for
  - 23-Na needs to be replaced by BNL
  - V improve integral performance
  - 243-Am(n,2n) total cross section (isomeric ratio is OK)
  - 143-Nd thermal & resonance region (Mughabghab)
  - 58-Co thermal region (Mughabghab)
- Testing needed Zr, Hf (naval programs)
ENDF/B-VII.1 release

- Release date December 2011
  - neutron sublibrary
  - decay data sublibrary
- Dedicated Nuclear Data Sheet issue
  - Big-Paper-II (library description, main reference)
  - Covariances (Don Smith)
  - Covariances for light nuclei (G. Hale)
  - Covariances for actinides (LANL)
  - Covariances for structural materials and fission products (BNL)
  - Covariances in resonance regions (ORNL)